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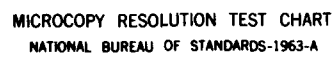   N LIPINSKA ET AL. 27 JUL 83 FTD-ID(RS)T-1094-83
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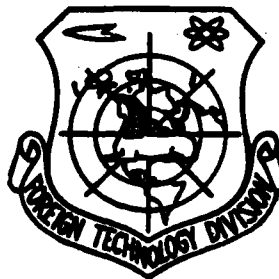NATIONAL BUREAU OF STANDARDS-1963-A

FOREIGN TECHNOLOGY DIVISION

STORAGE OF ENERGY IN MAGNETIC FIELD OF
SUPERCONDUCTIVE COILS

by

N. Lipinska and W. Lipinski

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STORAGE OF ENERGY IN MAGNETIC FIELD OF SUPERCONDUCTIVE COILS

Nina Lipinska and Wojciech Lipinski

Storage of electric energy is expensive, however, indispensable wherever the consumer wants to be independent of the power network. In many fields of engineering it is also required to release large quantities of energy in the form of short pulses. Selection of the storage method is related to the required power take-off and output characteristics of the stored energy, the duration of these processes, the density of the stored energy, economic considerations, etc.

The volume density of the energy of a magnetic field is relatively high; however, because of heat losses in windings of normally conductive coils, the latter are not suitable for storage of energy. One new method of storing electric energy that is currently being developed is the application of coils with windings made from superconductors. Energy can be stored in them without losses and utilized even in the form of a short pulse with high efficiency.

Superconductive air coils began to dominate presently used kinetic and electrostatic energy collectors, especially after the satisfactory design of switches $\sqrt{1}, 2\sqrt{}$.

Selection of the superconductive material is related to the type of operation of the system--slow or fast discharge, maximum current field magnitudes, stability, etc. The used superconductors must have a high critical temperature, and also the highest critical magnetic field magnitude. For most superconductors the critical magnitude of the magnetic field is not great. The latter makes it necessary to use thin layers whose thickness is smaller than the penetration depth of the magnetic field. Therefore the critical field magnitude is many times greater. Fig. 1 presents the magnitude of the product of the critical current density and magnetic induction for various superconductors.

The principal superconductors used at the present time are: Nb_3Sn, V_3Ga, and NbN.

Another problem during the introduction of superconductive coils is the problem of operational stability. A coil is made up of a dozen or so sections. The latter are charged sequentially and generate magnetic fields that are summed. If one section or a part of the section is no longer a superconductor, the heat generated at a current density on the order 10^4 A/cm^2 may lead to fusion of the material, an electric arc, and an additional avalanche reaction in the subsequent sections.

One proposed protection $/\overline{}2\_/$ involves switching over the damaged element to a high resistance located outside.

An accurate determination of the inductance and magnetodynamic effects requires a determination of the three-dimensional distribution of the magnetic field. The conducted theoretical and experimental studies took into account toroidal, spherical, and cylindrical coils $/\overline{}3\_/$.

Fig. 2a presents the cross-section of a toroidal coil. The magnetic field lines are closed inside the coil, forming circles whose centers lie on the coil axis. The stray field, similarly as in an infinitely long cylindrical coil, is equal to zero. The magnetodynamic forces are directed perpendicularly to the windings and to the direction of magnetic induction. A large stray
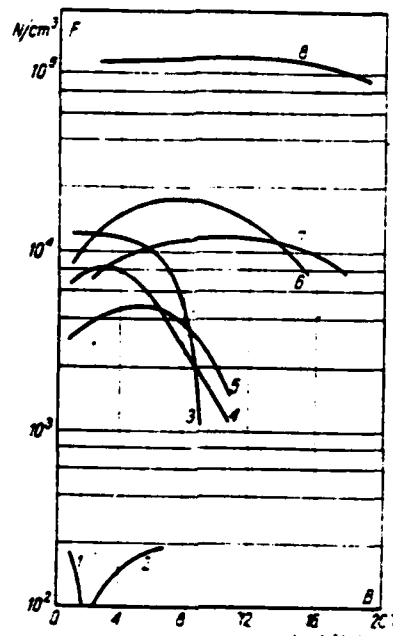
Fig. 1. Critical magnitude $F'' = J_k B$ versus induction B for the following materials:
1 -- niobium; 2 -- porous glass from PbBi;
3 -- Nb-40Zr-10Ti; 4 -- Nb-78Ti; 5 -- Nb61Ta;
6 -- Nb_2Sn; 7 -- V_3Ga; 8 -- NbN

field outside the coil occurs in the case of a cylindrical coil shown in

Fig. 2b. In relative terms, the spherical coil configuration appears to be

best (Fig. 2c). Unlike the case of the toroidal coil, here the stray field

is not equal to zero; however, the three-dimensional distribution of magneto-

dynamic forces disrupting the coil can be tackled more easily. In the case of

a spherical coil whose current density distribution along the winding is pro-

portional to the cosine of the polar angle in a spherical coordinate system,

a uniform magnetic field is obtained inside the coil /4, 5/.

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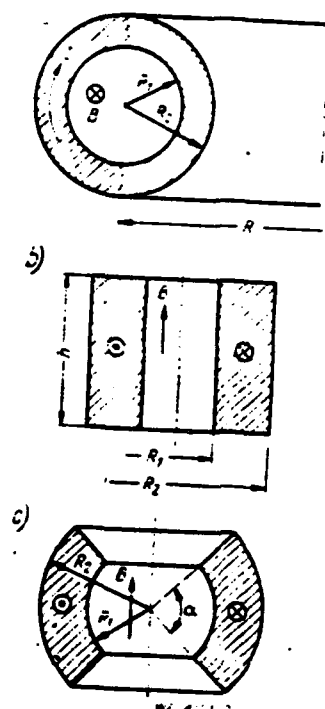Fig. 2. Superconductive coils:
a -- toroidal; b -- cylindrical;
c -- spherical

Reference $\underline{/\,1\,\underline{/}}$ presents an energy-storage capability which can be built theoretically at the present time (Fig. 3). Individual dashed cross-sections indicate individual coils in which the current density varies according to a cosine law. A uniform magnetic field prevails inside the coil: B = 10 T, which corresponds to 40 MJ/m^3. The maximum disruptive force is $3 \cdot 10^4$ N/cm^2, whereas the quantity of stored energy is about 10^{13} J, or 2800 MWh.
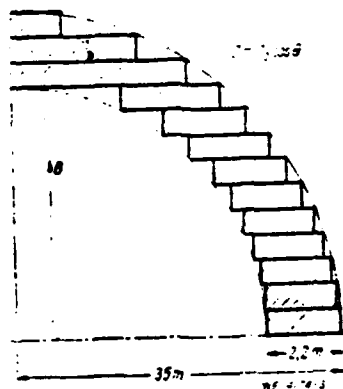
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Fig. 3. Configuration of spherical
energy storage

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